Radiation sensitive medium for recording an absorbed dose distribution

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(54) Title: RADIATION SENSITIVE MEDIUM FOR RECORDING AN ABSORBED DOSE DISTRIBUTION

(57) Abstract: The invention relates to a radiation sensitive medium for recording an absorbed dose distribution from an external radiation source such as e.g. a linear particle accelerator used for e.g. cancer treatment or radiation processing. The invention further relates to a method for measuring the absorbed doses distribution in a radiation sensitive medium.

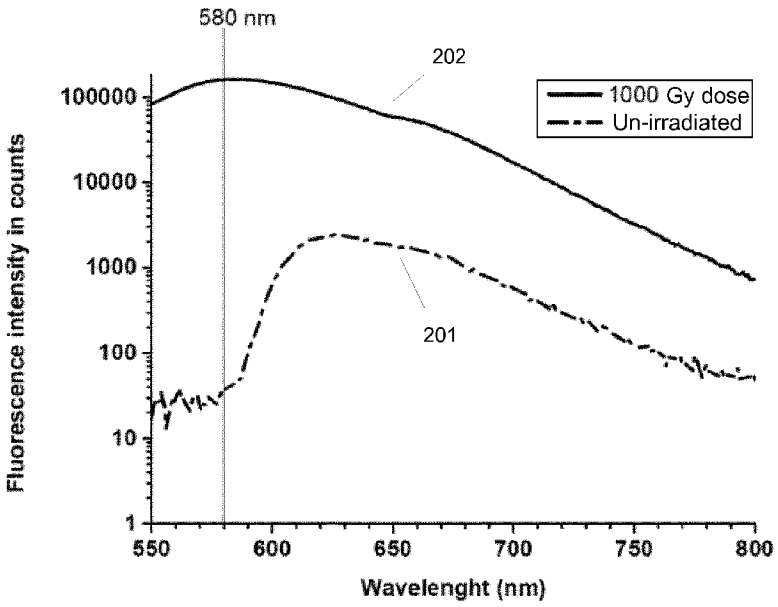

Fig. 2

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RADIATION SENSITIVE MEDIUM FOR RECORDING AN ABSORBED DOSE DISTRIBUTION

The invention relates to a radiation sensitive medium for recording an absorbed dose distribution from an external radiation source such as e.g. a linear particle accelerator used for e.g. cancer treatment or radiation processing, e.g. sterilization, modification or synthesis of materials by irradiation.

The invention further relates to a method for quantifying the recorded absorbed dose distribution in the radiation sensitive medium. The invention furthermore relates to nuclear track detection.

Background

Modern medical treatment using an external radiation source with high energy photon sources, electron sources, proton sources or similar uses complex radiation geometries and radiation sequences. The complexity of the radiation geometry and sequences inevitable introduces a risk of experiencing malfunctioning and/or inaccurate usage of the advanced equipment. The medical personal handling the equipment may also make calculation mistakes prior to treatment of a patient. The consequence of each of these risks are that a patient may by exposed to the wrong dose of radiation, which in worst case scenario may have fatal consequences for the patient.

Deviations in the radiation dose level provided to a patient of 5% or more is considered a very serious mistake which may have severe consequences for the patient. Also, subjecting the patient to radiation having the correct dose, but being provided to the patient at an incorrect position on the patient's body, may also have severe consequences.

Hospitals therefore have a need for a method and device for measuring the radiation dose, which the patient is to be exposed to, prior to actually exposing the patient to the radiation. This is also to ensure a high quality of radiation treatment and/or diagnostics in each treatment.

There is a number of existing systems which allows for online read-out of dose distributions. An example is the so called Delta-4 system from Scandidos. Common

for the different known systems are the use of one or more 2D-arrays of diodes of ion chambers whereby a 3D image of the dose distribution is obtained by combining the information obtained from the 2D-arrays. Such a combination of information form 2D-arrays is however not accurate. Systems using 2D diode arrays or ion chambers are usually also rather expensive and require a large amount of operational knowledge and skills in order to setup and use the system.

It is also known to use an optical CT system, e.g. 'OCTOPUS' from MGS Research Inc., which uses a colour changing (radiochromic) polymer material called PRESAGE for measuring the 3D dose distribution, which is read-out in an optical CT scanner. This method is however time consuming and cumbersome to work with. Further, the colour changing material is unstable over time, which means that the dose-distribution needs to be measured directly or after the same predetermined time interval after exposing the material to radiation from the external radiation source in order to ensure a reliable and consistent read-out, as described e.g. in *'Temperature dependence of the dose response…'* in Medical Physics, vol. 38 (2011) pages 2806-2811..

Further it is known to use gel-dosimeter technology where cross-links are formed in an aqueous polyacrylamide gel material. The amount and position of the formed cross-links are read-out using a magnetic resonance (MR) scanner, which makes this method expensive. Further, the number and position of the cross-links formed in the material are not stable over time due to diffusion within the material.

There is thus a need for a reliable, inexpensive and stable material and method for determining the absorbed dose-distribution from an external radiation source.

Description of the invention

Disclosed herein is a radiation sensitive medium for recording and storing a spatially absorbed dose distribution following irradiation by one or more beams comprising ionizing radiation from an external radiation source. The external radiation source may be a linear particle accelerator used for e.g. cancer treatment.

The radiation sensitive medium comprises one or more polymers being gas permeable, the one or more polymers including at least a first polymer. The radiation sensitive medium also comprises a first organic material containing a number of double bonds, and a second material. The second material may be a smaller molecule containing 5-10 atoms. The first organic material is normally a significantly larger molecule than the second molecule.

Upon exposure to radiation from the external radiation source, the first organic material is adapted for forming a stable free radical and a residual ion by an irreversible process. The second material is adapted for forming an additional ion, where the residual ion originating from the first organic material and the additional ion from the second material form a gas molecule. The gas molecule is able to diffuse out of the radiation sensitive medium. This ensures that the process remains irreversible and the free radical is stable.

When being excited at a first excitation wavelength within the visible wavelength range, the stable free radical fluoresces strongly at at least one luminescence wavelength, and luminescence from the first organic material at the at least one luminescence wavelength is insignificant.

By radiation sensitive medium is meant a block medium, pellets, small balls or other three dimensional media adapted to mimic e.g. the shape of a human body in the area where cancerous tissue is present, medical devices, food products or industrial products which are to be exposed to radiation. By three dimensional is not included films or similar thin objects.

By gas permeable is therefore meant that the gas permeability of the radiation sensitive medium allows the formed gas molecule to escape from the medium before the free radical and the residual ion has time to recombine to form the first organic material. Thus, the gas permeability of the medium must allow the free radical to remain a stable free radical over time.

The gas permeability of the one or more polymers and the subsequent irreversibility ensures that an extremely stable material for measuring the absorbed 3D dose

distribution is obtained. This is advantageous, as the read-out of the absorbed dose profile can be done at any given point in time as the profile does not change over time. Repeated measurements of the profile can also be performed at any given time.

The radiation sensitive medium only requires a translation stage and a camera with band-pass filter for read-out of the profile, which is significantly less expensive equipment compared to the requirements of an optical CT and MR scanners used in other methods. Further, when determining the absorbed dose-profile, a material only requiring luminescence measurements has the advantage that signal saturation issues can easily be addressed by adjusting the intensity or wavelength of the excitation light. This is a large advantage compared to using absorption measurements techniques, where saturation issues often can occur.

Disclosed herein is also the use of a radiation sensitive medium for recording and subsequently measuring the spatially absorbed dose distribution from an external radiation source, e.g. a radiation source linear particle accelerator used for cancer treatment or radiation processing.

Thus, disclosed herein is the use of a radiation sensitive medium for recording and subsequently measuring the spatially absorbed dose distribution from an external radiation source used for cancer treatment.

Disclosed herein also is the use of a radiation sensitive medium for recording and subsequently measuring the spatially absorbed dose distribution from an external radiation source used for radiation processing of sterilisation of disposable medical devices.

Disclosed herein further is the use of a radiation sensitive medium for recording and subsequently measuring the spatially absorbed dose distribution from an external radiation source used for radiation processing of surface treatment of polymers, e.g., making polystyrene hydrophilic.

Disclosed herein also is the use of a radiation sensitive medium for recording and subsequently measuring the spatially absorbed dose distribution from an external radiation source used for radiation processing of preventing food from bacterial decomposition.

Disclosed herein is further a method for measuring the spatially absorbed dose distribution from an external radiation source used e.g. for cancer treatment or radiation processing. The method comprises the step of providing a radiation sensitive medium comprising one or more polymers being gas permeable, the one or more polymers including at least a first polymer, a first organic material containing a number of double bonds, and a second material.

The method further comprises the step of exposing the radiation sensitive medium to radiation from the external radiation source used for cancer treatment or radiation processing for a pre-determined amount of time whereby the first organic material by an irreversible process forms a stable free radical and a residual ion by a non-reversible process, where the residual ion and an additional ion from the second material form a gas molecule, the gas molecule diffuses out of the radiation sensitive medium.

Subsequently, the method comprises the steps of ending the exposure to radiation from the external radiation source after the pre-determined amount of time, measuring luminescence from the radiation sensitive medium at least over a primary area of the radiation sensitive medium and at at least one luminescence wavelength after excitation at the first excitation wavelength, and determining the absorbed dose distribution with the radiation sensitive medium.

The gas permeability of the polymers and the subsequent irreversibility ensures that an extremely stable material for recording a 3D absorbed dose distribution is obtained. This is advantageous as the read-out of the 3D absorbed dose distribution profile can be done at any given point in time as the profile does not change over time. Repeated measurements of the profile can also be performed at any given time.

The recorded absorbed dose distribution only requires a camera with an optical bandpass filter for read-out of the profile, which is significantly less expensive equipment compared to the requirements of either optical CT or MR scanners used in other procedures. Further, when determining the absorbed dose profile, a material only requiring luminescence measurements has the advantage that signal saturation issues can easily be addressed by adjusting the intensity of the excitation light. This is a large advantage compared to using absorption measurements techniques, where saturation issues often can occur . To convert the recorded absorbed dose distribution into a 3D dose profile processing suitable data processing of the luminescence signal is required. This is done by in-house developed software.

Brief description of the drawings

Figure 1A shows the chemical structure of pararosaniline leuconitrile, which is an example of a first organic material being an organic material containing a number of double bonds.

Figure 1B shows the chemical structure of 1,1 diphenyl-2-picrylhydrazine, which is an example of a first organic material containing a number of double bonds, and figure 1C shows the free radical 2,2 diphenyl-1-picrylhydrazyl of 1,1 diphenyl-2-picrylhydrazine in figure 1B.

Figure 2 shows luminescence measurements in an example of the radiation sensitive medium before and after being exposed to radiation from an external radiation source.

Figure 3 shows the colour difference in an example of the radiation sensitive medium before and after being exposed to radiation.

Figure 4A-C show examples of one or more monomers, which upon photo curing forms the one or more polymers.

Figure 5A-B show examples of photo initiators.

Figure 6 shows an example of a photo initiator and its role in the photo curing reaction forming the one or more polymers.

Figure 7 shows the sensitivity of the radiochromic processes depending on the photo initiator chemistry.

Figure 8A-B show how the dose response of the polymer-based leuco-dye-doped state dosimeter can be linked to that of a standard dosimeter material like alanine using electron paramagnetic resonance (EPR) spectrometer to measure the presence of the radiation-induced free-radical.

Description of preferred embodiments

Disclosed herein is a radiation sensitive medium for recording and storing a spatially absorbed dose distribution following irradiation by one or more beams comprising ionizing radiation from an external radiation source.

In one or more embodiments, the radiation sensitive medium is solid.

The external radiation source may be a linear particle accelerator used for e.g. cancer treatment or radiation source for sterilisation.

In one or more embodiments the external radiation source is a radioactive source emitting α-rays, β-rays, γ-rays or Auger electrons. An example of a γ-ray emitting source is a Co-60 source.

Alternatively, in one or more embodiments, the external radiation source is a linear accelerator emitting X-rays, electrons.

Yet alternatively, in one or more embodiments, the external radiation source is a particle beam, e.g. a proton radiation source. Neutron radiation sources may also be used. Further, heavy-ion radiation sources may be used.

In one or more embodiments, the external radiation source emits electrons with energies between 1-300 kV.

In one or more embodiments, the external radiation source emits electrons, X-rays or γ-rays with energies between 5-20 MV, or 6-18 MV.

In one or more embodiments, the external radiation source emits protons with energies between 70-250 MeV.

In one or more embodiments, the external radiation source emits heavy-ions like Carbon with energies up to 3 GeV.

In one or more embodiments, the external radiation source emits neutrons with energies between 50-70 MeV.

The external radiation source will normally emit radiation providing an absorbed dosis between 1-50 Gy for medical applications and 10-100 kGy for radiation processing.

The radiation sensitive medium can assume different geometrical shapes depending on its use. A square shape or round shape may be used, but a number of other shapes may also be imagined. Thus, the radiation sensitive medium may be a block medium, pellets, small balls or other three dimensional media adapted to mimic e.g. the shape of a human body in the area where cancerous tissue is present, medical devices, food products or industrial products which are to be exposed to radiation. By three dimensional is not included films or similar thin objects. The radiation sensitive medium will be solid.

In one or more embodiments, the radiation sensitive medium has a minimum thickness of 0.5 mm.

In one or more embodiments, the radiation sensitive medium has a shape mimicking that of elongated pellets. The elongated pellets may be between 1-10 mm in thickness and 1-20 mm in length.

In one or more embodiments, the radiation sensitive medium has a block shape. The radiation sensitive medium may have a minimum thickness of 10 cm.

The radiation sensitive medium comprises different materials including one or more polymers. There is typically one dominating polymer referred to as the first polymer. All the polymers in the radiation sensitive medium will normally be gas permeable. In one or more embodiments, all the polymers in the radiation sensitive medium are gas permeable.

The radiation sensitive medium also comprises a first organic material containing a number of double bonds. The double bonds are normally conjugated double bonds.

The radiation sensitive medium also comprises a second material. The second material is normally a smaller molecule containing 5-10 atoms, whereas the first organic material is normally a significantly larger molecule than the second molecule.

In one or more embodiments the second material is a proton donating material.

In one or more embodiments the second material is selected from the group of citric acid, acetic acid or halogenated hydrocarbon compounds. The group of halogenated hydrocarbon compounds may include chloral hydrate, chloroform, tetrachloromethane, chlorobenzene, dichlorobenzene, trichlorobenzene, tetrachlorobenzene and tetrachloro-1,4-benzoquinone.

When the first organic material is exposed to radiation from the one or more external radiation sources, the first organic material is adapted for forming a stable free radical and a residual ion by an irreversible process illustrated below, where the first organic material is denoted $\boldsymbol{R-X}$, the free stable radical denoted $\boldsymbol{R^*}$, and the residual ion denoted $\boldsymbol{X^-}$:

$$\boldsymbol{R-X} \xrightarrow{\text{radition from an external radiation source}} \boldsymbol{R^* + X^-} \qquad [1]$$

The second material is capable of donating an ion M^+, which can react with residual ion X^- to form a small gas molecule:

$$X^- + M^+ \rightarrow XM\,(g) \qquad [2]$$

The gas molecule is able to diffuse out of the radiation sensitive medium. This ensures that the process remains irreversible and the free radical is stable. The process becomes irreversible as the formed gas molecule is able to diffuse out of the radiation sensitive medium due to the gas permeability of the one or more polymers. This ensures that the residual ion and the stable free radical cannot re-connect to form the first organic material over time. By gas permeability of the radiation sensitive medium is therefore meant that the formed gas molecule (***XM***) can escape from the radiation sensitive medium before the free radical and the residual ion has time to recombine to form the first organic material. Thus, the gas permeability of the radiation sensitive medium must allow the free radical (***R****) to remain a stable free radical over time.

It follows from the above that an extremely stable material for storing/recording the absorbed 3D dose distribution is obtained. Advantageously, the read-out of the absorbed dose distribution can be done at any given point in time as the distribution does not change over time. Repeated measurements of the profile can also be performed at any given time.

The radiation sensitive medium is normally a three dimensional object such as e.g. a block medium, pellets, small balls or other three dimensional media adapted to mimic e.g. the shape of a human body in the area where cancerous tissue is present, medical devices, food products or industrial products which are to be exposed to radiation. By three dimensional is not included films or similar thin objects.

In one or more embodiments, the first organic material is a leuco dye material. Thus, the first organics material is colourless in its original state, but becomes coloured when transformed into a free radical.

In one or more embodiments, the first organic material contains a nitrile functional group. This is advantageous as the nitrile ion is then separated from the first organic material and subsequently able to combine with e.g. a hydrogen ion from the second material by the below reactions:

$$\boldsymbol{R-C\equiv N \xrightarrow{\text{radition from an external radiation source}} R^{*}+C\equiv N^{-}} \quad [3]$$

$$\boldsymbol{C\equiv N^{-}+H^{+}\rightarrow HCN\,(g)} \quad [4]$$

Hydrogen cyanide may subsequently diffuse out of the radiation sensitive medium due to the gas permeability of the one or more polymers.

As an alternative to using a hydrogen ion donating material as the second material, a metal ion donating material capable of donating a metal ion, may also be used. An example of such material could donate a silver ion, a gold ion or similar, which together with the cyanide ion will form AgCN or AuCN, respectively. The metal-cyanide compound will not diffuse out of the material, but instead form extremely stable complexes and in this way ensure that the reaction in [1] remains irreversible, as it is not possible for the cyanide ion to react with the radical ($\boldsymbol{R^{*}}$). For examples of first organic materials, which form a stable free radical and another negative ion not being the cyanide ion, the negative ion may also form a compound which precipitates accordingly:

$$\boldsymbol{X^{-}+M^{+}\rightarrow XM\,(solid)} \quad [4]$$

In one or more embodiments the first organic material is pararosaniline leuconitrile as shown in figure 1A. Pararosaniline leuconitrile is nearly colourless and can be described as a leuco-dye. As seen in figure 3, the colour of the stable free radical is red, which means that it is not nearly colourless like pararosaniline leuconitrile.

The high amount of double bonds in pararosaniline leuconitrile provides for a stable radical formation after the cyanide ion is detached from the structure due exposure to radiation. The cyanide ion is marked in figure 1A with the circle 102.

Figure 1B shows the chemical structure of 1,1 diphenyl-2-picrylhydrazine, which is another example of a first organic material containing a number of double bonds. This example of a first organic material is also a colourless leuco-dye, which only absorbs insignificantly little of the visible light, but it is does not contain a nitrile group.

The stable free radical 2,2 diphenyl-1-picrylhydrazyl shown in figure 1C instead has a strong blue colour meaning that it absorbs an amount of visible light. Further, 2,2 diphenyl-1-picrylhydrazyl fluoresces strongly when excited at a first excitation wavelength contrary to 1,1 diphenyl-2-picrylhydrazine.

When being excited at a first excitation wavelength within the visible wavelength range, the stable free radical formed from the first organic material, e.g. pararosaniline leuconitrile and 2,2 diphenyl-1-picrylhydrazyl, luminesces strongly at at least one luminescence wavelength. Contrary to the luminescence from the stable free radical, luminescence from the first organic material at the at least one luminescence wavelength is insignificant. This allows the user to clearly distinguish the areas in the radiation sensitive medium, which have been exposed to ionising radiation from those that have not or have only been exposed to ionising radiation to a smaller extend in a subsequent analysis of the radiation sensitive medium. By luminescence is normally meant fluorescence, delayed fluorescence or phosphorescence.

Figure 2 shows luminescence measurements of the radiation sensitive medium with pararosaniline leuconitrile as the first organic material both before being exposed to ionising radiation 201 and after being exposed to radiation 202 from a Co-60 gamma radiation source providing a dose of 1000 Gy. In the experiment, fluorescence is the primary luminescence.

The luminescence measurement shown figure 2 takes only around 1 second to perform. The second material, which is used for donating the hydrogen ion is in this example citric acid. Materials, which donates a chloride ion when exposed to ionised

radiation, where the chloride ion reacts with water to form hydrogen chloride, which again serves as a hydrogen donating material, may also be used.

The first polymer used in the radiation sensitive medium used for the measurement in figure 2 is poly(ethylene glycol) diacrylate and the second polymer is 2-hydroxyethylmethacrylate.

The luminescence signal shown on a logarithmic scale shows a significant difference between the luminescence intensity using an excitation wavelength at 532 nm, where the un-irradiated sample displays an insignificant luminescence compared to that from the irradiated sample.

In one or more embodiments, the excitation wavelength is found within the wavelength between 300-800 nm, such as e.g. between 400-700 nm, such as e.g. between 500-600 nm, such as e.g. between 500-550 nm, such as e.g. between 400-600 nm, such as e.g. between 400-500 nm, such as e.g. between 600-700 nm, such as e.g. between 700-800 nm, such as e.g. between 300-500 nm, or such as e.g. between 300-400 nm.

In one or more embodiments, the at least one luminescence wavelength is found within the wavelength between 300-800 nm, such as e.g. between 400-700 nm, such as e.g. between 500-600 nm, such as e.g. between 500-550 nm, such as e.g. between 400-600 nm, such as e.g. between 400-500 nm, such as e.g. between 600-700 nm, such as e.g. between 700-800 nm, such as e.g. between 300-500 nm, or such as e.g. between 300-400 nm.

The luminescence signal has further shown to scale proportionally with intensity of the radiation. Thus, in one or more embodiments the concentration of the stable free radical increases as the dose from the external radiation source increases, thereby increasing luminescence signal measurable at the at least one luminescence wavelength.

The radiation sensitive medium only requires a camera with an optical bandpass filter for read-out of the profile, which are significantly less expensive equipment

compared to the requirements of optical CT and MR scanners used in other methods. Further, when determining the absorbed dose-profile, a material only requiring luminescence measurements has the advantage that signal saturation issues can easily be addressed by adjusting the intensity of the excitation light. This is a large advantage compared to using absorption measurements techniques, where saturation issues often can occur.

The absorption spectrum of the radiation sensitive medium with pararosaniline leuconitrile as the first organic material changes upon being exposed to radiation from e.g. a Co-60 gamma radiation source providing a dose of 1000 Gy. This can be seen in the photos shown in figure 3, where a clear colour difference can be seen in the radiation sensitive medium before being exposed to radiation 301 and after being exposed to radiation 302 from a Co-60 gamma radiation source providing an absorbed dose of 1000 Gy to the radiation sensitive medium. The material with stable free radicals 302 has a more red absorption profile compared to the un-irradiated material 301 without any stable free radicals. After irradiation, the material remains stable.

In one or more embodiments the one or more polymers forms a matrix adapted for restricting diffusion of the stable free radical within the radiation sensitive medium. When using a first organic material such as e.g. pararosaniline leuconitrile shown in figure 1A, the movement of the aniline and phenyl groups are restricted by the one or more polymers – in particular the stable free radical of pararosaniline leuconitrile. Thus, in one or more embodiments, the one or more polymers forms a matrix adapted for restricting internal rotational properties of the stable free radical.

The restricted movement of the stable free radical contributes to the observation of strong luminescence from the stable free radical.

At the same time as restricting the movement of the first organic material within the radiation sensitive medium, the one or more polymers forms a matrix adapted for allowing the residual ion and the additional ion from the second material to diffuse freely within the matrix, and allowing the gas molecule to diffuse out of the radiation sensitive medium.

By the above described structure, a radiation sensitive medium which provides a detection method with a spatial resolution down to 0.1 mm combined with a low uncertainty in the accuracy of the result of down to 1 % is obtainable. In fact it is most likely the equipment that sets the limits for the resolution, as the radiation sensitive medium itself should be able to provide resolutions down to and even below 100 nm.

In one or more embodiments the first polymer is hydrophilic. This is advantageous since water molecules are required for the formation of radicals due to ionising radiation.

Examples of the first polymer include polyvinyl alcohol (PVA), polyvinyl pyrrolidone (PVP), poly-(poly ethylene glycol) diacrylates (poly-PEG diacrylates), and the polymers of 2-hydroxyethylmethacrylate, polyethylene dimethacrylate, tripropylene glycoldiacrylate, and tripropylene glycoldimethacrylate.

Thus, in one or more embodiments, the first polymer is selected from the group of polyvinyl alcohol, polyvinyl pyrrolidone, poly-polyethylene dimethacrylate, poly-tripropylene glycoldiacrylate, poly-tripropylene glycoldimethacrylate, or poly-poly(ethylene glycol) diacrylate.

In one or more embodiments, the one or more polymers include a second polymer. The purpose of the second polymer is to confer mechanical stability of the dosimeter material. Thus, the second polymer is a stabilising polymer.

In one or more embodiments, the second polymer is selected from polymers formed from the monomeric building block group of 2-hydroxyethylmethacrylate, triethylene glycol diacrylate, triethylene glycol dimethacrylate, 1,6-hexanediol diacrylate, 1,6-hexanediol dimethacrylate, trimethylol propane triacrylate, trimethylol propane trimethyacrylate, pentaerythritol triacrylate, pentaerythritol trimethacrylate, trimethylolpropane ethoxytriacrylate, trimethylolpropane propoxytriacrylate, tris (2-hydroxyethyl) Isocyanurate triacrylate, pentaerythritol tetraacrylate,

ditrimethylolpropane tetraacrylate, and dipentaerythriol (monohydroxy) pentaacrylate.

It may also be imagined that the group of first polymer also include stabilizing polymers. Thus, the first polymer may further be selected from polymers formed from the monomeric building block group of 2-hydroxyethylmethacrylate, triethylene glycol diacrylate, triethylene glycol dimethacrylate, 1,6-hexanediol diacrylate, 1,6-hexanediol dimethacrylate, trimethylol propane triacrylate, trimethylol propane trimethyacrylate, pentaerythritol triacrylate, pentaerythritol trimethacrylate, trimethylolpropane ethoxytriacrylate, trimethylolpropane propoxytriacrylate, tris (2-hydroxyethyl) Isocyanurate triacrylate, pentaerythritol tetraacrylate, ditrimethylolpropane tetraacrylate, and dipentaerythriol (monohydroxy) pentaacrylate.

In one or more embodiments, the one or more polymers comprises a third polymer. The third polymer is for increasing the dielectric constant of the radiation sensitive medium. The purpose of using a state sensitive medium with high dielectric constant is to enhance the radiochromic process and to increase the Stokes shift between the absorption peak of the stable free radical and the peak of the fluorescence emitted by the stable free radical.

Figures 4A-C show example of monomers which may be used as the building blocks for the third polymer with a high dielectric constant. The monomeric building blocks are 1,3,5-triallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione in figure 4A, N-vinyl pyrrolidone (e.g. 1-vinyl-2-pyrrolidone) in figure 4B, and propylene carbonate in figure 4C. Thus, in one or more embodiments, the third polymer is selected from the group of poly-1,3,5-triallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, poly-N-vinyl pyrrolidone (e.g. 1-vinyl-2-pyrrolidone), and poly-propylene carbonate.

When preparing the the radiation sensitive medium, the monomeric building blocks for forming the one or more polymers, are used.

In one or more embodiments the radiation sensitive medium is light curable.

By light curable is meant that the one or more monomeric building blocks for forming the one or more polymers in the radiation sensitive medium are light curable, and that the radiation sensitive medium is obtained by photo curing of the monomeric building blocks.

Thus, in one or more embodiments, one or more monomeric building blocks for forming the one or more polymers in the radiation sensitive medium are light curable.

The light curing property of the medium is conferred by the presence of a photo initiator. This gives a very large design freedom for the user, as all kinds of shapes and formats can be created depending on application needs. It is thereby possible to make both films and blocks in a number of shapes and sizes, e.g. to mimic the shape of a patient, which is to receive radiation treatment. As the proposed material is light curable, arbitrary shapes can be generated by the use of a 3D printer.

Thus, in one or more embodiments, the radiation sensitive medium further comprises a photo initiator for initiating photo curing of the one or more monomeric building blocks in the radiation sensitive medium.

The photo initiator used needs to be excited by wavelengths outside the absorption spectrum of the first materiel, e.g. pararosaniline leuconitrile. Useful photoinitiators include ,e.g., camphorquinone, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide, 4-(dimethylamino)benzophenone, phenanthrenequinone, trimethylbenzoylphospine oxide, isopropylthioxanthone, and ethyl-4-(dimethylamino) benzoate.

Thus, in one or more embodiments, the photo-initiator is selected from the group of camphorquinone, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide, 4-(dimethylamino)benzophenone, phenanthrenequinone, trimethylbenzoylphospine oxide, isopropylthioxanthone, and ethyl-4-(dimethylamino) benzoate.

Figure 5A-B show examples of the photo initiators isopropylthioxanthone (ITX) shown in figure 5A and ethyl-4-(dimethylamino) benzoate (EDB) shown in figure 5B.

Originally, the use of a photo initiator was intended to facilitate an easy method for curing the starting material to form the radiation sensitive medium containing the radiation sensitive first organic material. However, the reaction products formed by the photo initiator may also act as scintillators. Therefore, there is an additional reaction where the fragments formed from the light curing process of the photo initiator acts as scintillators. The effect of the scintillators is that UV photons are emitted when the radiation sensitive medium is irradiated by ionising radiation. The UV photons will also cause the first organic material to form free radicals through the process of photo-ionisation.

The effect of the photo initiator on the first organic material is shown in figure 6, where the photo initiator trimethylbenzoylphospine oxide 202 upon exposure to actinic radiation (hυ) forms two radicals, 2,4,6-trimethylbenzoyl denoted 204 and diphenylphosphonyl denoted 206, whereof 2,4,6-trimethylbenzoyl 204 reacts with the first organic molecule 210 to form 2,4,6-trimethylbenzaldehyde 208 and the stable free radical 212.

The fragments from the photo initiator reaction described above and shown in figure 6 increases the sensitivity of the radiation sensitive medium as shown in figure 7 showing the absorbance peak as a function of the absorbed dose for two different concentrations of the photo initiator trimethylbenzoylphospine oxide (TPO). The photo initiator ITX contains sulphur in the molecular structure. This facilitates formation of the triplet state, which is advantageous when using the material as photo initiator, but not preferable for use in the radiation sensitive medium, as it acts as a quencher for fluorescence.

In one or more embodiments the radiation sensitive medium further comprises one or more reference point(s) for determining the positioning within the radiation sensitive medium, wherein the one or more reference points are obtained by exposing the radiation sensitive medium to laser radiation strong enough for generating localised two-photon absorption reference points prior to the use of the radiation sensitive medium for recording and storing a spatially absorbed dose distribution, wherein when the one or more reference points are exposed to light at a

second excitation wavelength reference signals relating to the dose distribution area and positioning within the radiation sensitive medium is obtainable.

The one or more reference points may be made directly in the radiation sensitive medium by exposing the medium to a focused femtosecond laser, e.g. emitting light at 670 nm, whereby two-photon absorption may occur, which results in the creation of the reference points in a very specific location of the material. This is done prior to the use of the radiation sensitive medium for recording and storing a spatially absorbed dose distribution following irradiation by one or more beams comprising ionizing radiation from an external radiation source.

The second excitation wavelength may be identical to the first excitation wavelength, but may also be different. The second excitation wavelength may e.g. be a wavelength inducing luminescence in the reference point material, but only resulting in insignificant luminescence from the stable free radical.

When the reference points are created by focussing a laser beam inside the medium by the use of two-photon excitation, the process of creating the reference points will not affect the recorded absorbed dose distribution in the medium.

When creating a specific shape / block of the radiation sensitive medium, a number of reference points may be positioned at predetermined positions/locations in the shape / block relative to each other. This provides the user with reference points with known internal distances.

Having reference points in the radiation sensitive medium allows for a precise determination of the relative position of the part of the radiation sensitive medium, which have been exposed to radiation, when knowing before-hand the exact location of the reference points in the block made from the radiation sensitive medium. Thereby a precise 3D profile of the absorbed dose distribution can be obtained after exposing a block of the radiation sensitive medium to ionizing radiation.

One pertinent issue when working with dosimeters is traceability. Figure 8A-B show how the dose response of the polymer-based leuco-dye-doped state dosimeter can be linked to that of a standard dosimeter material like alanine using electron paramagnetic resonance (EPR) spectrometer to measure the presence of the radiation-induced free-radical. Thus, an independent method is available for measuring the amount of free-radical formed by irradiating the radiation sensitive medium.

Figure 8A shows the EPR spectrum of pellets of alanine and figure 8B shows the EPR spectrum of pellets of pararosaniline leuconitrile in a polyethyleneglycol diacrylate polymer medium. The pellets have the same size with 4.75 mm in diameter and a thickness of 2.78 mm.

The non-linear response (inhibition) of the EPR dose measurements in figure 8B is most likely caused by formation of free radicals from residual photo initiator. Using alanine, a pure free radical source, as a reference material during the development of the radiation sensitive medium of this invention allows for an elucidation of the finer details of the dose response of the new radiation sensitive medium according to this invention.

In one or more embodiments, the radiation sensitive medium is used for recording and subsequently measuring the absorbed dose distribution from an external radiation source, e.g. a radiation source linear particle accelerator used for cancer treatment or radiation processing.

Disclosed herein is also a method for measuring the absorbed dose distribution from an external radiation source used e.g. for cancer treatment or radiation processing. The method comprises the steps of first providing a radiation sensitive medium comprising:

- one or more polymers being gas permeable, the one or more polymers including at least a first polymer,
- a first organic material being an organic material containing a number of double bonds, and
- a second material,

as described above.

After providing the radiation sensitive medium, it is exposed to radiation from the external radiation source used for cancer treatment or radiation processing for a pre-determined amount of time. Thereby the first organic material forms a stable free radical and a residual ion by an irreversible process. The residual ion and an additional ion from the second material form a gas molecule, which is able to diffuse out of the radiation sensitive medium.

After exposing the radiation sensitive medium to ionising radiation, the exposure to radiation from the external radiation source is ended after the pre-determined amount of time. The luminescence from the radiation sensitive medium is subsequently measured at least over a primary area of the radiation sensitive medium and at at least one luminescence wavelength after excitation at the first excitation wavelength. From the luminescence measurements, determining the absorbed dose distribution with the radiation sensitive medium can be performed.

In one or more embodiments, measuring luminescence from the radiation sensitive medium is performed by scanning at least the first excitation wavelength over a three dimensional area of the radiation sensitive medium.

In one or more embodiments, the radiation sensitive medium is obtained by light curing a solution comprising one or more monomeric buildings blocks for forming the one or more polymers being gas permeable, the first organic material, and second material.

Claims

1. A radiation sensitive medium for recording and storing a spatially absorbed dose distribution following irradiation by one or more beams comprising ionizing radiation from an external radiation source, the radiation sensitive medium comprising:
   - one or more polymers being gas permeable, the one or more polymers including at least a first polymer,
   - a first organic material containing a number of double bonds, wherein upon exposure to radiation from the external radiation source, the first organic material is adapted for forming a stable free radical and a residual ion by an irreversible process, and
   - a second material adapted for forming an additional ion,

   wherein the residual ion originating from the first organic material and the additional ion from the second material form a gas molecule, the gas molecule being able to diffuse out of the radiation sensitive medium,
   wherein when being excited at a first excitation wavelength within the visible wavelength range:
   - the stable free radical fluoresces strongly at at least one luminescence wavelength, and
   - luminescence from the first organic material at the at least one luminescence wavelength is insignificant.

2. A radiation sensitive medium according to claim 1, wherein the radiation sensitive medium is solid.

3. A radiation sensitive medium according to claim 1 or 2, wherein the concentration of the stable free radical increases as the doses from the external radiation source increases, thereby increasing luminescence signal measurable at the at least one luminescence wavelength.

4. A radiation sensitive medium according to any preceding claim, wherein the second material is a proton donating material.

5. A radiation sensitive medium according to claim 4, wherein the second material is selected from the group of citric acid, acetic acid or halogenated hydrocarbon compounds.

6. A radiation sensitive medium according to claim 5, wherein the group of halogenated hydrocarbon compounds include chloral hydrate, chloroform, tetrachloromethane, chlorobenzene, dichlorobenzene, trichlorobenzene, tetrachlorobenzene and tetrachloro-1,4-benzoquinone.

7. A radiation sensitive medium according to any preceding claim, wherein the first polymer is hydrophilic.

8. A radiation sensitive medium according to any preceding claim, wherein the first polymer is selected from the group of polyvinyl alcohol, polyvinyl pyrrolidone, poly-polyethylene dimethacrylate, poly-tripropylene glycoldiacrylate, poly-tripropylene glycoldimethacrylate, or poly-poly(ethylene glycol) diacrylate.

9. A radiation sensitive medium according to any preceding claim, wherein the one or more polymers include a stabilising second polymer.

10. A radiation sensitive medium according to claim 9, wherein the second polymer is selected from polymers formed from the monomeric building block group of 2-hydroxyethylmethacrylate, triethylene glycol diacrylate, triethylene glycol dimethacrylate, 1,6-hexanediol diacrylate, 1,6-hexanediol dimethacrylate, trimethylol propane triacrylate, trimethylol propane trimethyacrylate, pentaerythritol triacrylate, pentaerythritol trimethacrylate, trimethylolpropane ethoxytriacrylate, trimethylolpropane propoxytriacrylate, tris (2-hydroxyethyl) Isocyanurate triacrylate, pentaerythritol tetraacrylate, ditrimethylolpropane tetraacrylate, and dipentaerythriol (monohydroxy) pentaacrylate.

11. A radiation sensitive medium according to any preceding claim, wherein the one or more polymers comprises a third polymer for increasing the dielectric constant of the radiation sensitive medium.

12. A radiation sensitive medium according to claim 11, wherein the third polymer is selected from the group of poly-1,3,5-triallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione, poly-N-vinyl pyrrolidone aka 1-vinyl-2-pyrrolidone, and poly-propylene carbonate.

13. A radiation sensitive medium according to any preceding claim, wherein one or more monomeric building blocks for forming the one or more polymers in the radiation sensitive medium are light curable.

14. A radiation sensitive medium according to claim 13 further comprising a photo-initiator for initiating photo curing of the one or more monomeric building blocks in the radiation sensitive medium.

15. A radiation sensitive medium according to claim 14, wherein the photo-initiator is selected from the group of camphorquinone, diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide, 4-(dimethylamino)benzophenone, phenanthrenequinone, trimethylbenzoylphospine oxide, isopropylthioxanthone, or ethyl-4-(dimethylamino) benzoate.

16. A radiation sensitive medium according to any preceding claim, wherein the first organic material is a leuco dye material.

17. A radiation sensitive medium according to any preceding claim, wherein the first organic material is a nitrile containing material.

18. A radiation sensitive medium according to any preceding claim, wherein the first organic material is selected from the group of pararosaniline leuconitrile, or 1,1-diphenyl-2-picrylhydrazine.

19. A radiation sensitive medium according to any preceding claim, wherein the one or more polymers forms a matrix adapted for:
    - restricting diffusion of the stable free radical within the radiation sensitive medium,
    - restricting internal rotational properties of the stable free radical,

- allowing the residual ion and the additional ion from the second material to diffuse freely within the matrix, and
- allowing the gas molecule to diffuse out of the radiation sensitive medium.

20. A radiation sensitive medium according to any preceding claim, wherein the radiation sensitive medium further comprises one or more reference points for determining the positioning within the radiation sensitive medium, wherein the one or more reference points are obtained by exposing the radiation sensitive medium to laser radiation strong enough for generating localised two-photon absorption reference points prior to the use of the radiation sensitive medium for recording and storing a spatially absorbed dose distribution, wherein when the one or more reference points are exposed to light at a second excitation wavelength reference signals relating to the dose distribution area and positioning within the radiation sensitive medium.

21. A radiation sensitive medium according to any preceding claim wherein the radiation sensitive medium has a minimum thickness of 0.5 mm.

22. A radiation sensitive medium according to any preceding claim wherein the radiation sensitive medium has a shape mimicking that of elongated pellets.

23. A radiation sensitive medium according to claim 22 wherein the elongated pellets are between 1-10 mm in thickness and 1-20 mm in length.

24. A radiation sensitive medium according to any of the claims 1-21 wherein the radiation sensitive medium has a block shape.

25. A radiation sensitive medium according to claim 24 wherein the radiation sensitive medium has a minimum thickness of 10 cm.

26. Use of a radiation sensitive medium according to any of the claims 1-25 for recording and subsequently measuring the spatially absorbed dose distribution

from an external radiation source, e.g. a radiation source linear particle accelerator used for cancer treatment or radiation processing.

27. Use of a radiation sensitive medium according to claim 26 for recording and subsequently measuring the spatially absorbed dose distribution from an external radiation source used for cancer treatment.

28. Use of a radiation sensitive medium according to claim 26 for radiation processing of sterilisation of disposable medical devices.

29. Use of a radiation sensitive medium according to claim 26 for radiation processing of surface treatment of polymers, e.g., making polystyrene hydrophilic.

30. Use of a radiation sensitive medium according to claim 26 for radiation processing of preventing food from bacterial decomposition.

31. Method for measuring the spatially absorbed dose distribution from an external radiation source used e.g. for cancer treatment or radiation processing, the method comprising the steps of:
    - providing a radiation sensitive medium comprising:
        - one or more polymers being gas permeable, the one or more polymers including at least a first polymer,
        - a first organic material containing a number of double bonds, and
        - a second material conferring mechanical stability to the radiation sensitive medium,
    - exposing the radiation sensitive medium to radiation from the external radiation source used for cancer treatment or radiation processing for a pre-determined amount of time whereby the first organic material by an irreversible process forms a stable free radical and a residual ion by a non-reversible process, where the residual ion and an additional ion from the second material form a gas molecule, the gas molecule diffuses out of the radiation sensitive medium, and

- ending the exposure to radiation from the external radiation source after the pre-determined amount of time;
- measuring luminescence from the radiation sensitive medium at least over a primary area of the radiation sensitive medium and at at least one luminescence wavelength after excitation at the first excitation wavelength, and
- determining the absorbed dose distribution with the radiation sensitive medium.

32. Method according to claim 31 wherein measuring luminescence from the radiation sensitive medium is performed by scanning at least the first excitation wavelength over a three dimensional area of the radiation sensitive medium.

33. Method according to claim 31 or 32 wherein the external radiation source is one of the following external radiation sources:
    - a radioactive source emitting α-rays, β-rays, γ-rays or Auger electrons
    - a linear accelerator emitting X-rays or electrons, or
    - a particle beam radiation source.

34. Method according to any of the claims 31-33 wherein the external radiation source emits electrons with energies between 1-300 kV.

35. Method according to any of the claims 31-33 wherein the external radiation source emits protons with energies between 70-250 MeV.

36. Method according to any of the claims 31-33 wherein the external radiation source emits heavy-ions like Carbon with energies up to 3 GeV.

37. Method according to any of the claims 31-33 wherein the external radiation source emits neutrons with energies between 50-70 MeV.

38. Method according to any of the claims 31-33 wherein the external radiation source emits electrons, X-rays or γ-rays with energies between 5-20 MV, or 6-18 MV.

39. Method according to any of the claims 31-38 wherein the radiation sensitive medium is obtained by light curing a solution comprising the first organic material, the second material, and one or more monomers forming the one or more gas permeable polymers

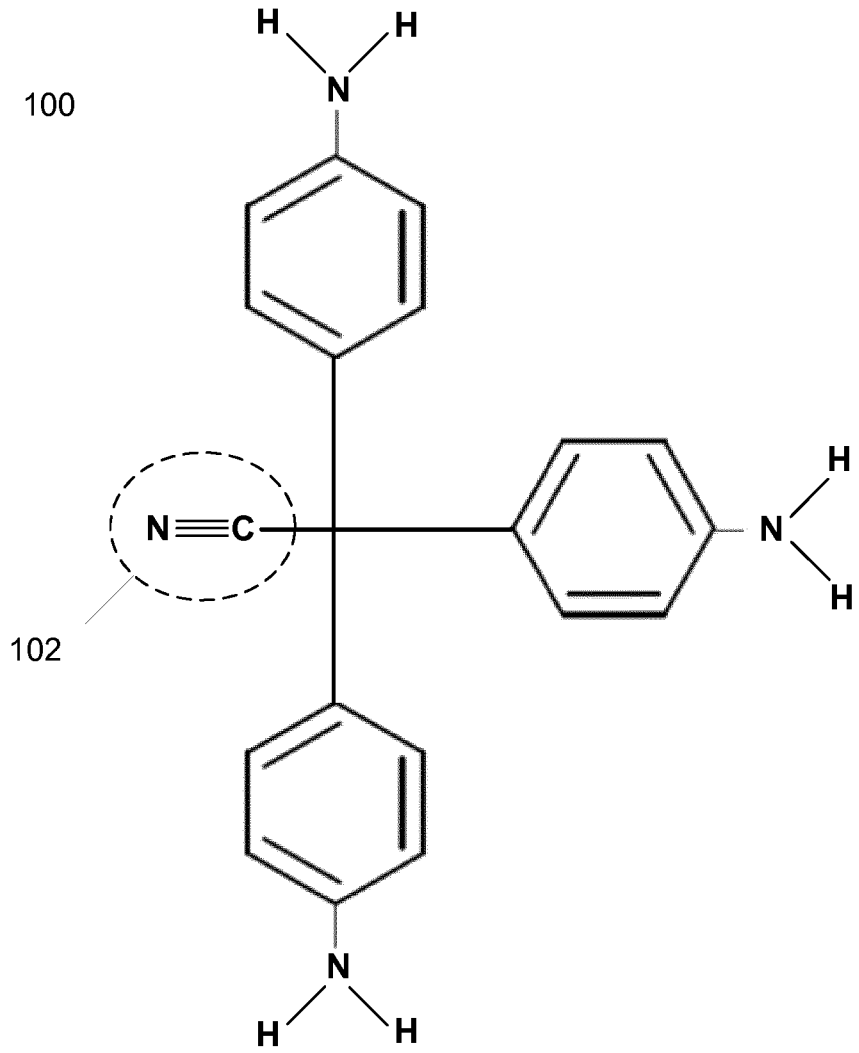


Fig. 1A

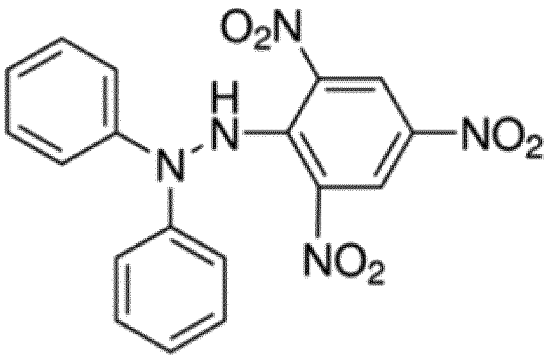


Fig. 1B

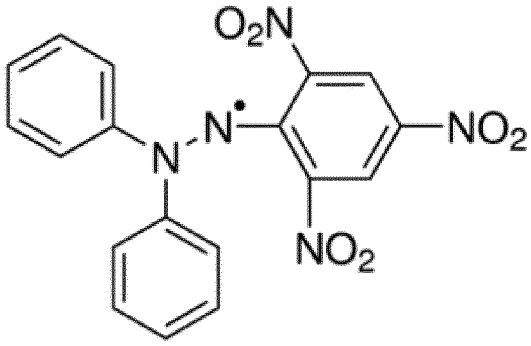


Fig. 1C

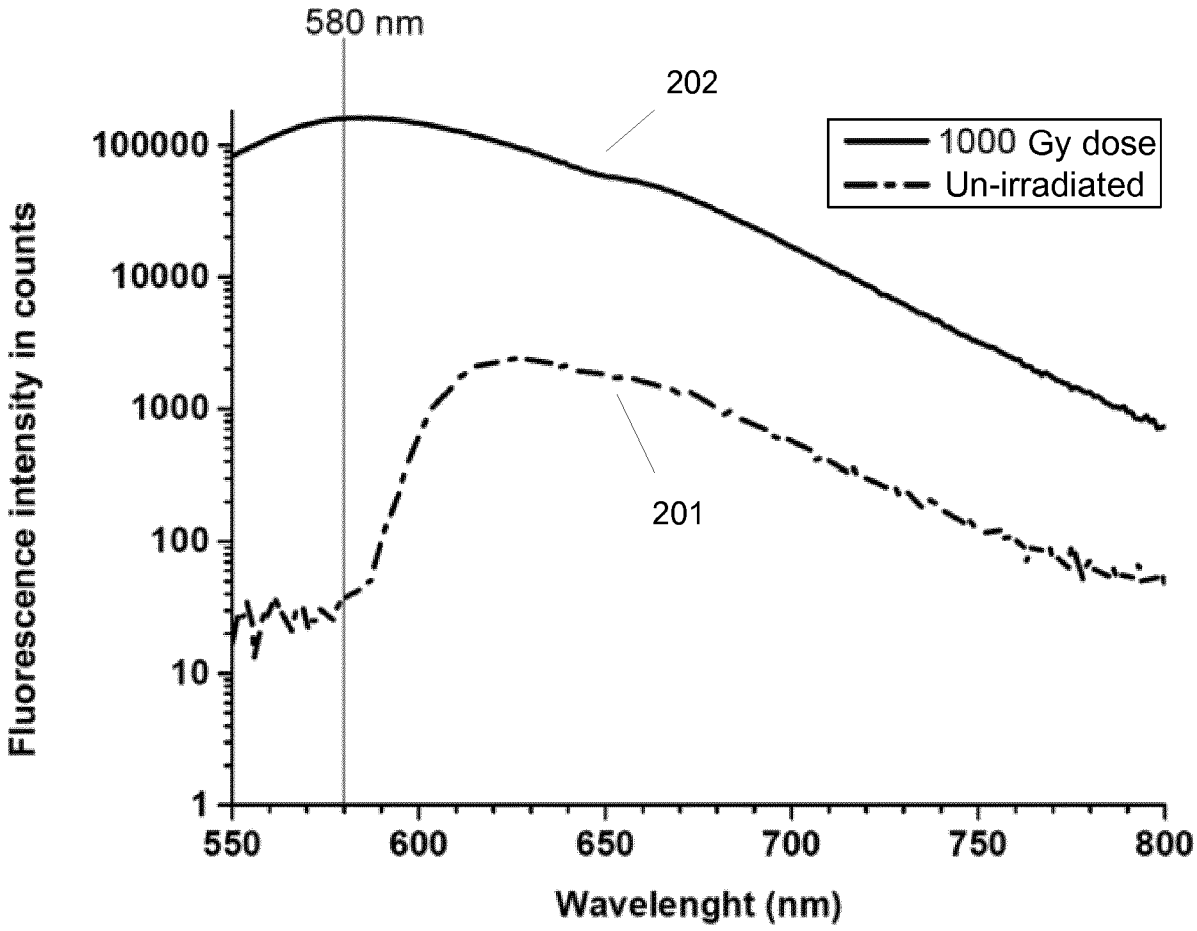

580 nm
202
1000 Gy dose
Un-irradiated
100000
10000
1000
100
10
1
201
Fluorescence intensity in counts
550
600
650
700
750
800
Wavelenght (nm)

Fig. 2

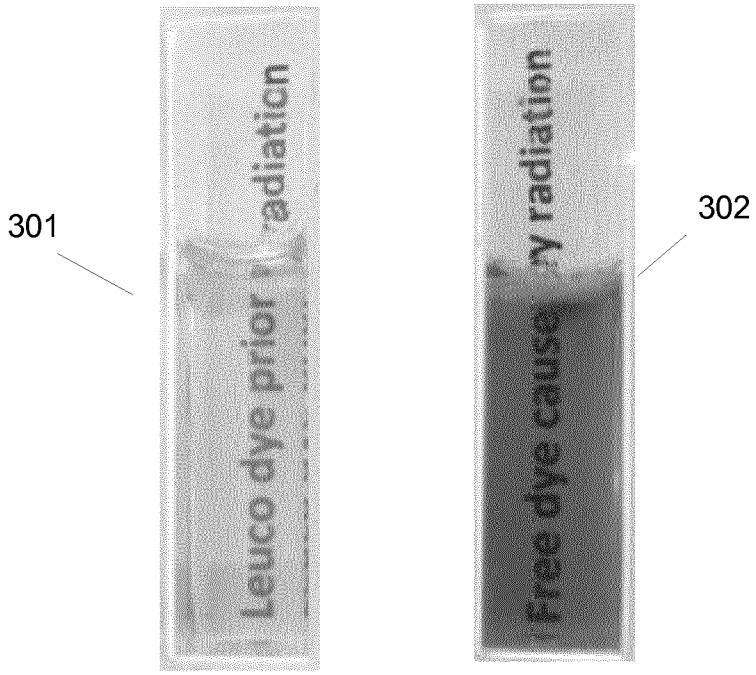

301
302
Leuco dye prior
radiation
Free dye caus
y radiation

Fig. 3

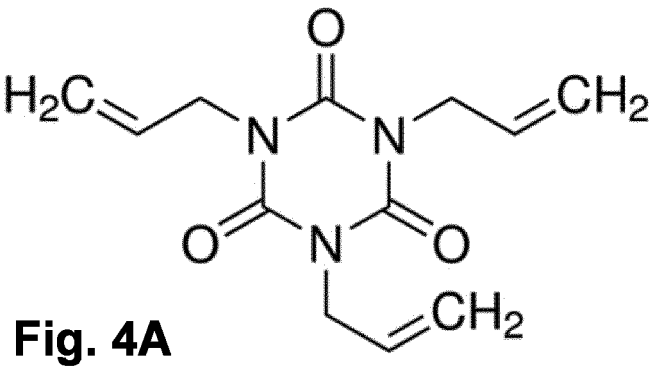


Fig. 4A

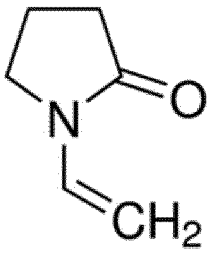


Fig. 4B

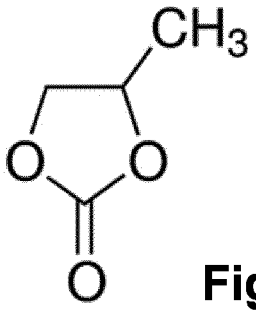


Fig. 4C

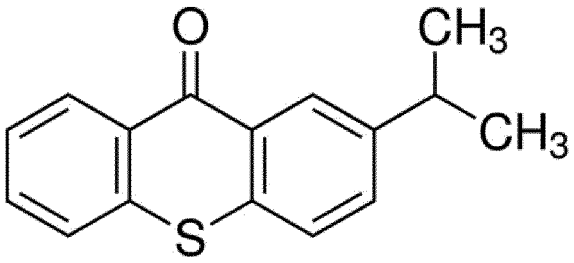


Fig. 5A

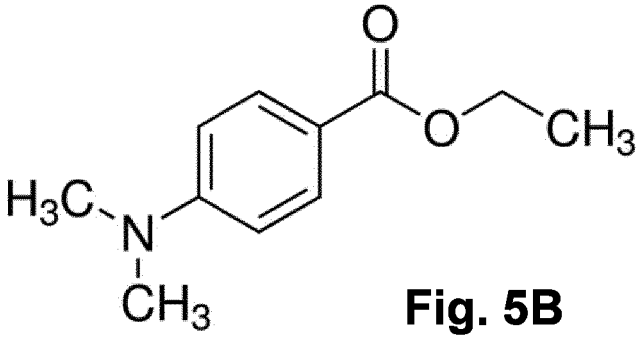
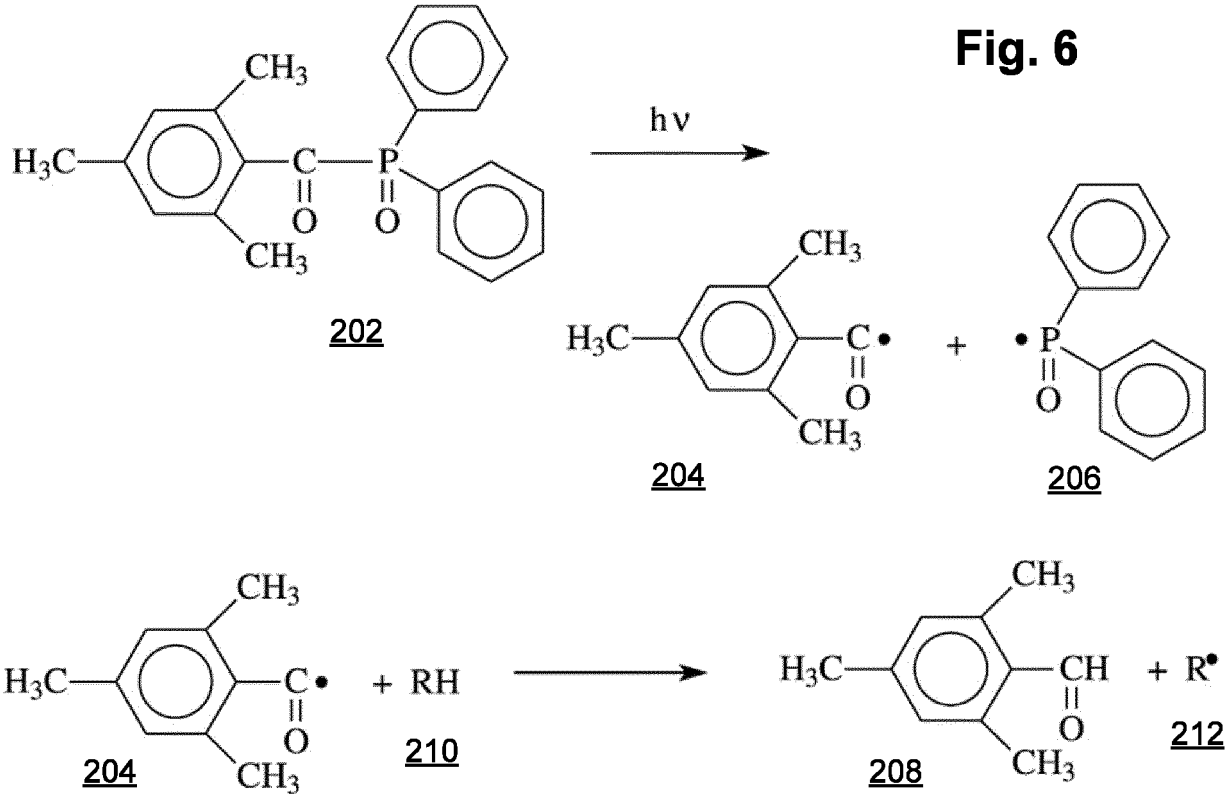


Fig. 5B

Fig. 6


CH3
H3C
C
O
P
O
CH3
hν
202
CH3
H3C
C•
O
CH3
+
• P
O
204
206
CH3
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C•
O
CH3
+ RH
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CH3
H3C
CH
O
CH3
+ R•
208
212

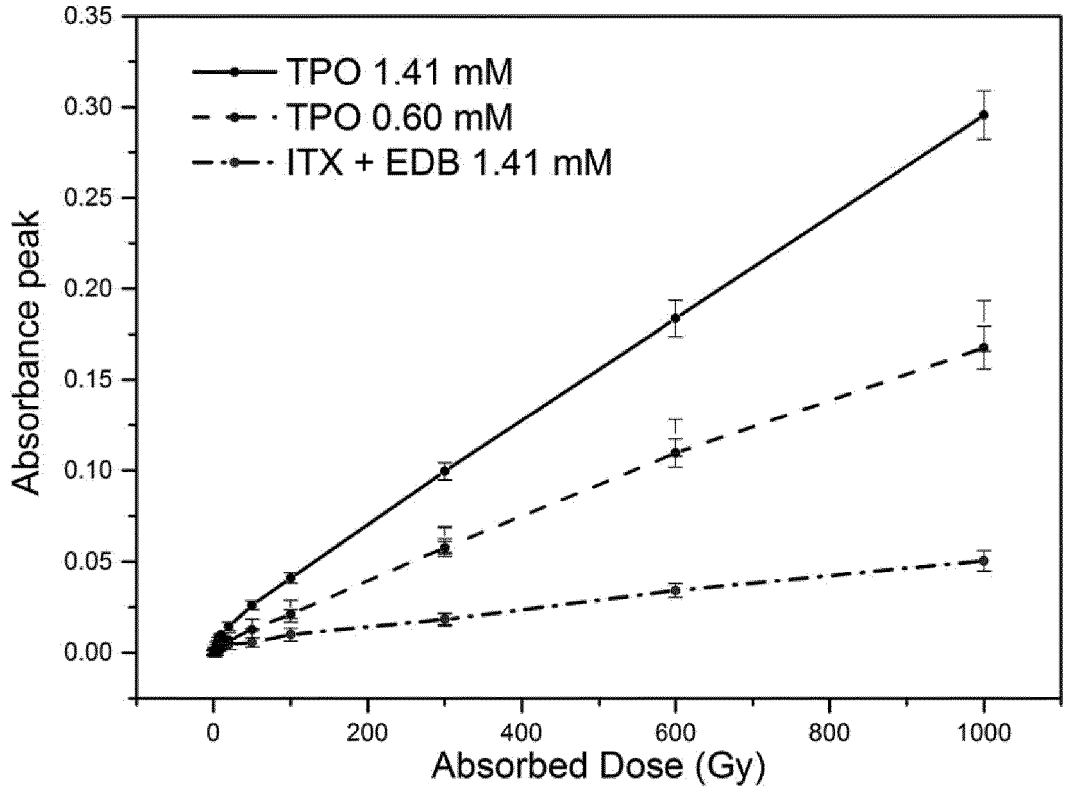
TPO 1.41 mM
TPO 0.60 mM
ITX + EDB 1.41 mM
Absorbance peak
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
200
400
600
800
1000
Absorbed Dose (Gy)

Fig. 7

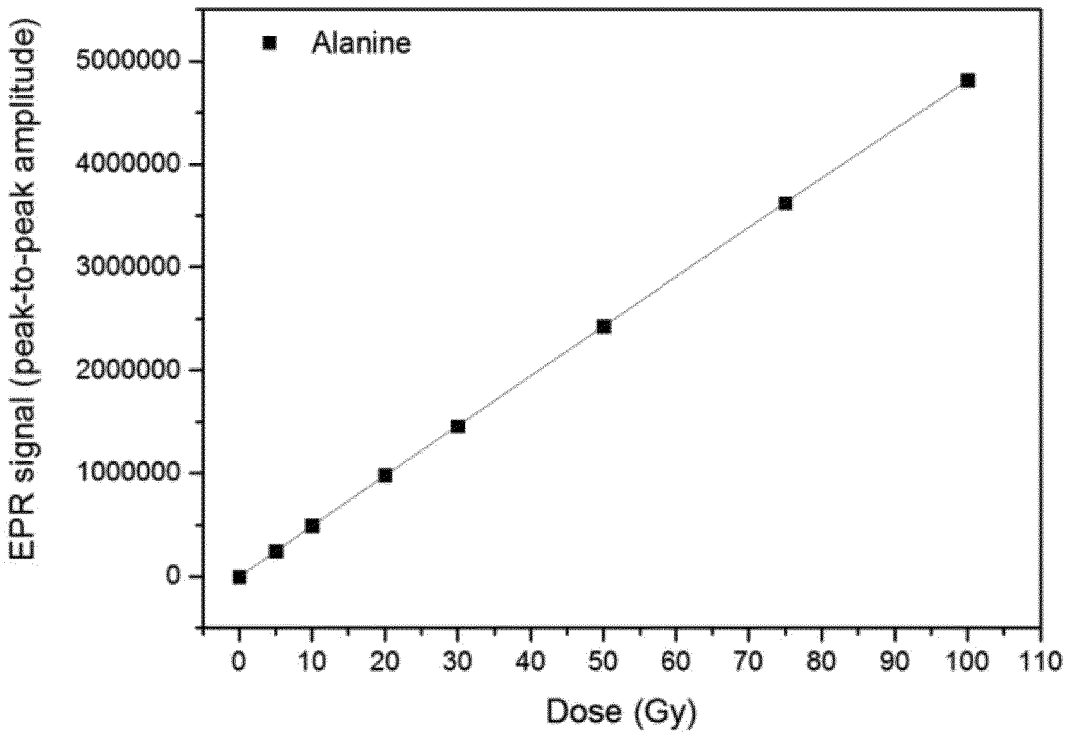
Alanine
EPR signal (peak-to-peak amplitude)
5000000
4000000
3000000
2000000
1000000
0
0
10
20
30
40
50
60
70
80
90
100
110
Dose (Gy)

Fig. 8A

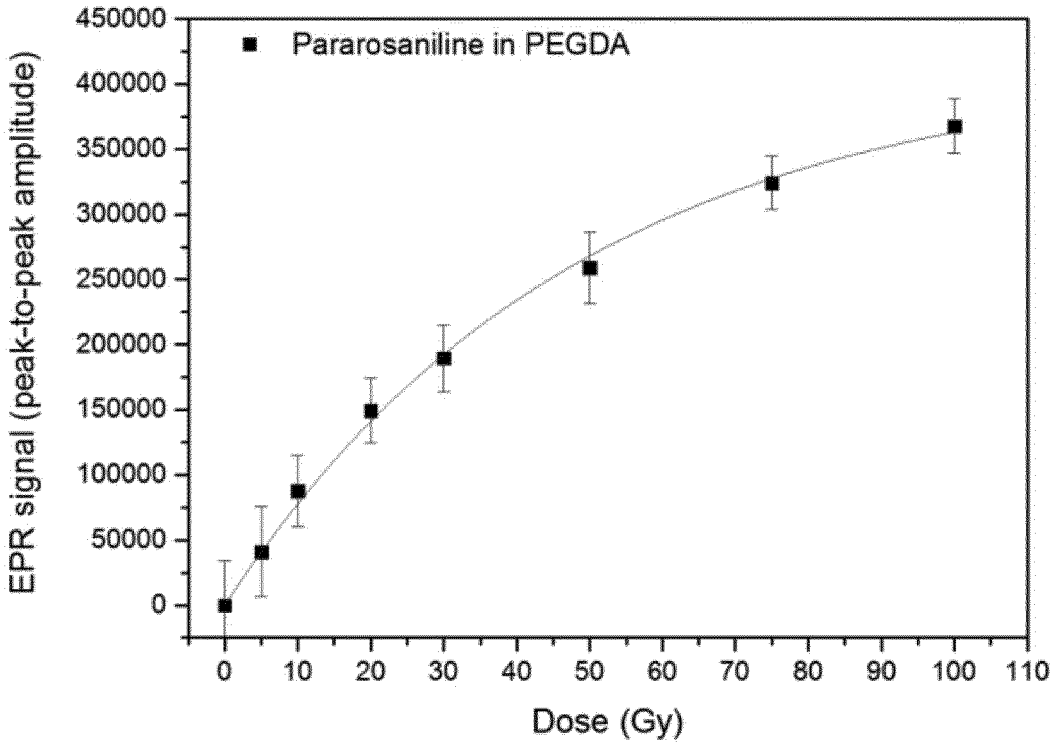
Pararosaniline in PEGDA
EPR signal (peak-to-peak amplitude)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0
10
20
30
40
50
60
70
80
90
100
110
Dose (Gy)

Fig. 8B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/081722

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01T1/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 202 323 A (HERZ MATTHEW L [US] ET AL) 13 May 1980 (1980-05-13) column 1, line 6 - line 17 column 2, line 7 - line 10 column 3, line 13 - line 22 column 4, line 5 - line 53; figures ----- -/--	1,26,31

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 February 2017	02/05/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Eberle, Katja

1

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	MCLAUGHLIN W L ET AL: "The gamma-ray response of pararosaniline cyanide dosimeter solutions", INTERNATIONAL JOURNAL OF APPLIED RADIATION AND ISOTOPS, PERGAMON PRESS, NEW YORK, NY, US, vol. 25, no. 6, 1 June 1974 (1974-06-01), pages 249-262, XP024717912, ISSN: 0020-708X, DOI: 10.1016/0020-708X(74)90092-1 [retrieved on 1974-06-01] abstract page 251	1,26,31
X	EP 2 172 752 A1 (TESA AG [DE]) 7 April 2010 (2010-04-07) abstract paragraph [0006] paragraph [0014] - paragraph [0015] paragraph [0094] - paragraph [0095] paragraph [0102] paragraph [0115]	1-4,7, 13-19, 26-34,39
A	WO 2004/079393 A2 (HEURIS PHARMA LLC [US]) 16 September 2004 (2004-09-16) page 19, line 31 - page 20, line 26	10
Y	US 8 115 182 B1 (PATEL GORDHANBHAI N [US]) 14 February 2012 (2012-02-14) column 33, last paragraph - column 34, paragraph first	10
X	US 4 006 023 A (MCLAUGHLIN WILLIAM L ET AL) 1 February 1977 (1977-02-01)	1-9, 11-14, 16,17, 19,21-38
Y	abstract; figures column 1, line 6 - line 8 column 1, line 29 - line 52 column 1, line 60 - column 2, line 34 column 2, line 62 - line 67 column 3, line 56 - line 64 column 4, line 18 - line 59; examples column 5, line 18 - line 21	10

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2016/081722

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-19, 21-39

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-19, 21-39

A radiation sensitive medium for recording and storing a spatially absorbed dose distribution comprising:
- one or more polymers being gas permeable, including at least a first polymer,
- a first organic material containing a number of double bonds for forming a stable free radical and a residual ion by an irreversible process, and
- a second material adapted for forming an additional ion, wherein the residual ion originating from the first organic material and the additional ion from the second material form a gas molecule being able to diffuse out of the radiation sensitive medium, wherein when being excited at a first excitation wavelength within the visible wavelength range:- the stable free radical fluoresces strongly at at least one luminescence wavelength, and- luminescence from the first organic material at the at least one luminescence wavelength is insignificant wherin the medium further comprises a stabilising second polymer

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2. claim: 20

A radiation sensitive medium for recording and storing a spatially absorbed dose distribution comprising:
- one or more polymers being gas permeable, including at least a first polymer,
- a first organic material containing a number of double bonds for forming a stable free radical and a residual ion by an irreversible process, and
- a second material adapted for forming an additional ion, wherein the residual ion originating from the first organic material and the additional ion from the second material form a gas molecule being able to diffuse out of the radiation sensitive medium, wherein when being excited at a first excitation wavelength within the visible wavelength range:- the stable free radical fluoresces strongly at at least one luminescence wavelength, and- luminescence from the first organic material at the at least one luminescence wavelength is insignificant wherein the medium further comprises one or more reference points

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/081722

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